A7: Size Estimates, Extinction Dates, Altaba 2014 and Réunion Fossil Localities

Body-Mass and Size Estimates

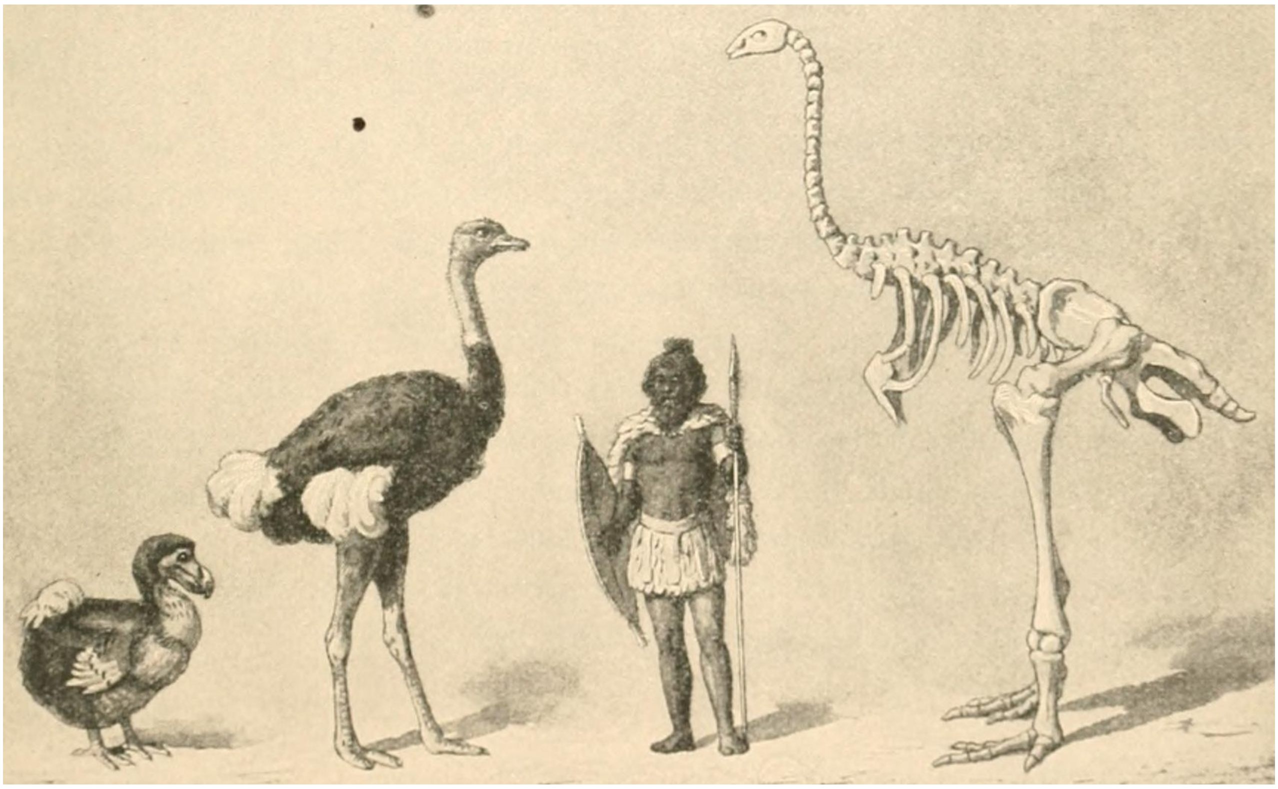
The following are body-mass and size estimates for the dodo and solitaire given by previous authors.

Raphus cucullatus
Body-mass:
Herbert (1634): "few weigh lesse then fifty pound" (22.68kg).
25lb (Weinland 1863); 12.5kg (Leunis 1883; Potonié 1895); up to 25 pounds (Noll 1889); 25kg, *Pezophaps* likewise (Lambrecht 1933); about 12.5kg (Obenberger 1935); about 22.5kg (Lüttschwager 1972); at least 12kg (Temple 1977); over 30 pounds (13.62kg; Temple 1983); 25lb or more (Gould 1992); 10 to maximum 22kg (Van Wissen 1995); 30lb (Quammen 1996); *c*.10-22kg (Gill & West 2001); between 10 and 22kg (Fuller 2002); 24-40lb (10.5-17.5kg), some estimates up to 50lb (22.5kg) (Lowther 2002); *c*.13-20kg (Dissanayake 2004); average 14.3kg (Grihault 2005).

Height:
2½ feet high (Weinland 1863); "about the height of a large turkey" (Clark 1865); reached a height of 80cm (Leunis 1883); 2½ feet (76.2cm; Noll 1889); approx. 80cm (Potonié 1895); *c*.80cm high (Leche 1907); about 1m (Hoffmann [Naber] 1931); 75cm high, *Pezophaps* likewise (Lambrecht 1933); nearly three feet tall (91.44cm; Temple 1983); approx. 70cm (Cornuault 1997); about 75cm high (Gill & West 2001); height approx. 72cm, length approx. 72cm (Fuller 2002); 30" high (76.2cm; Leunis 1860); 40 in. (100cm) (Lowther 2002); standing about 70cm tall (Dissanayake 2004); 70-100cm, depending on gender and posture (Kallio 2005); 70-75cm (Grihault 2007); approximately 70-75cm (28-29in; Hume & Walters 2012); 1m (Van 't Hof 2014).

Length:
almost 3 feet (Donndorff 1793); ~100cm (Fuller 1987); typical length 1m (39in.; Walker & Ward 1992).

Head length: 17cm (6¾in.; Walker & Ward 1992). Bill length: 8in. (20cm: Crome 2002). Preserved head 23cm long (Dissanayake 2004).



The dodo shown to scale with an ostrich, a man and the skeleton of a moa (Cory 1899, p.1).

Pezophaps solitaria
Body-mass:
As much as 62lb (28kg: Crome 2002); 28kg (male), 17kg (female) (Rodríguez-Pontes 2014, citing Livezey 1993).

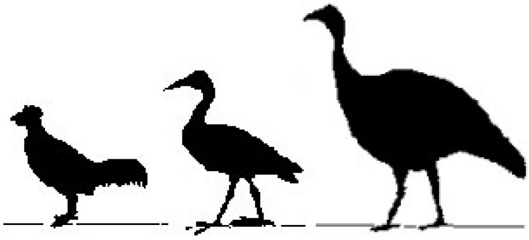
Height:
38 inches (96.4cm) (Strickland 1853: "the measurements of the *Goura* [femur, tibiotarsus and tarsometatarsus] are very nearly half those of the *Pezophaps*, and as the *Goura* when living measures about 19 inches [48.2cm] from the ground to the crown of the head, we may assume the Solitaire to have been about 38 inches in height, a stature which sufficiently corresponds with the descriptions of Leguat and D'Heguerty" (p.194); largest males stood 2 feet 9 inches high (83.82cm), females at least 6 inches (15.24cm) shorter (Newton & Gadow 1896); about 1m (2½ feet) (Killermann 1915); overall height 1m, height at pelvis 70cm (Lüttschwager 1961, based on mounted skeletons); 85-90cm (Grihault 2007); approximately 70cm (27.5in) in female, 90cm (35.5in) in male (Hume & Walters 2012); 90cm (male), 70cm (female) (Rodríguez-Pontes 2014, citing Livezey 1993).

Length:
~90cm (Fuller 1987).

Caldwell's solitaire skeletons measured as follows: male 2 feet 9 inches (83.82cm), female 2 feet 3¼ inches (69.22cm) (Item 28, Indian Ocean MS. volume, Balfour and Newton Libraries, University of Cambridge).

Raphus solitarius
Length:
~100cm (Fuller 1987).

Threskiornis solitarius
Bodymass: 2.9-3.5kg (Mourer-Chauviré *et al.* 2000 – based on the equation of Campbell & Marcus 1992); approx. 3kg (Brial 2006).[1]
Legnth: total length from tip of beak to tail 64-84cm (Brial 2006, based on same dimensions as sacred ibis (*ex* Del Hoyo *et al.* 1996) but with shorter beak); "no more than 65cm in total (the size of the Sacred Ibis Threskiornis aethiopicus)" (Hume & Walters 2012, p.114).
According to Brial (2006), the Réunion solitaire was more robust than *Threskiornis aethiopicus*.
Diameter of the tarsometatarsus is 20% greater than that of *Threskiornis aethiopicus* (Brial 2006).



Size comparison of domestic cock, Réunion solitaire (ibis) and turkey (Brial 2006, p.64. © Pierre Brial).

Additional References

Hoyo, J. del, Elliott, A. & Sargatal, J. 1996 Handbook of the Birds of the World, *Lynx Edicions, Barcelona*.

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[1] The Réunion solitaire was compared to a turkey cock by Tatton and Carré. Brial (1998) stated that these weigh 10kg, although Mourer-Chauviré *et al.* (2000) pointed out that the average weight of a male turkey is 7.4kg and added that domestic turkeys, as known to 17th-century travellers to Réunion, were much smaller than wild turkeys.

Extinction Dates

The following are dates suggested for the extinction of the dodo, solitaire and Réunion solitaire by previous authors.

Dodo

Extinction date: 1630s (Mlíkovský 2010a); 1640s on the mainland and around 1662 on Ile d'Ambre (Cheke 2006); "*c.*1640s on mainland, 1662 on offshore islet; some claim 1680s (disputed)" (Cheke 2013b, p.14); by 1660 (Middleton 1997); 1660s (Kitchener 1990, 1993a, b); 1662 (Cheke 2014, on Île d'Ambre; 1640s on the mainland); about 1662 (Knox & Walters 1994); probably between 1662 and 1693 (Kallio 2005); probably *c.*1665 (Van Wissen 1995); by 1670 (Lowther 2002); no later than 1670s (Van Wissen 1995); 1679 (Obenberger 1935; Lüttschwager 1959; Kuhn 1971); probably disappeared from Mauritius by 1673 (Milne-Edwards 1869, Olson 1977); 1679 (Leunis 1860); around 1679 (De Wit 1940); between 1679 and 1693 (Milne-Edwards 1866b); by 1680 (North-Coombes 1979); <1681 (Knox & Walters 1994); *c.*1680 (Sclater 1915; Jouanin 1962, 1966; Walters 1980; Day 1989); by 1681 (Temple 1977); about 1681 (Fisher & Peterson 1964; Murton 1974; North-Coombes 1979); 1681 (Oudemans 1918b); between 1681 and 1693 (Schlegel 1866; Hachisuka 1953; Ley 1957a); about 1690 (Vinson 1968); ± 1690 (Oudemans 1917d); by about 1690 "if not earlier" (Quammen 1996, p.263); by about 1693 (Cowles 1987; Fuller 1987).

Cauche, in 1640, was "the last visitor to claim to have seen a Dodo on the Mauritian mainland" (Cheke 1987, p.38).

Müllenmeister (1981) stated that: "towards the end of the 17th century the Dodo was already rare, in the early 18th century there were still some specimens in animal preserves, and around the middle of the 18th century it had already become extinct" (p.51).

Last known sighting: Evertsz (1662: (J.F.) R.O. 1985; Cheke 1987; Ziswler 1996; Gill & West 2001; Roberts & Solow 2003; Roberts 2013 [Île d'Ambre]; Van 't Hof 2014); Simon the slave (1663-1674: Pitot 1914); Harry (1681: Newton 1875-89; Salvadori 1893; Wood 1927; Renshaw 1931; Hachisuka 1953; Ley 1957a; Iwanow 1958; Silverberg 1967; Das 1973; Luna de Carvalho 1989; Gould 1992); 1679 (Lambrecht 1933). Harry's (1681) account is the last definite mention of the dodo (Hume 2006).

Rodrigues Solitaire

Extinction date: approx. 1730 (Sibley 1955); about 1760 (Brial 2006); by 1760 (Middleton 1997); probably became extinct 1760-1790 (Oliver 1891); presumably in 1760s (Cheke 1987); probably around 1760s (Hume & Walters 2012); probably by the late 1760s (Hume in Cheke & Hume 2008); *c.*1760 (-1765? Cheke 2013b); by 1770 (Lowther 2002), around 1770 (North-Coombes 1979), *c.*1780 (Schlegel 1854b; Day 1989; Grihault 2005); about 1790 (Jouanin 1962, 1966); about 1791 (Fisher & Peterson 1964; Brodkorb 1971; Murton 1974); *c.*1800 (Walters 1980); sometime during the second half of the eighteenth century (Fuller 1987, 2002). Last reliable date: 1760 (Knox & Walters 1994).

Réunion Solitaire

around 1640 [!] (Grihault 2005); *c.*1700 (*Ornithaptera solitarius*: Day 1989; Grihault 2005); shortly after 1700 (Probst 1997); shortly after 1708 (Hume in Cheke & Hume 2008); "by the early 1700s the few remaining birds were prevented from breeding by introduced predators, and died out around 1710-1715" (Cheke 1987, p.40); by 1710-15 (Cheke & Hume 2008); probably between 1710 and 1746 (Probst & Brial 2001 [*Threskiornis solitarius*]); possibly between 1714 and 1735 (Brial 2006)[2]; 1715 (Clements 1991); *c.*1715 (Cheke 2013b); between 1735 and 1801 (Rothschild 1907); White Dodo was last seen in 1740 (Kruyfhooft 1986); about 1746 (Fisher & Peterson 1964); about 1746 (*Raphus solitarius*: Brodkorb 1971; Murton 1974); *c.*1750 (Jouanin 1962, 1966 [*Raphus solitarius*]; Greenway 1967; Walters 1980); by 1750 (Lowther 2002); probably survived until 1750 (*Raphus solitarius*: Fuller 1987); around the middle of the 18th century (Wolters 1982); *c.*1770 (*Victoriornis imperialis*: Day 1989; Grihault 2005); at the end of the eighteenth century (white Réunion dodo: Wood 1927). Last reliable date: 1708 (Cheke 1987); 1710 (Knox & Walters 1994). The white dodo of Réunion was seen for the last time around 1740 (Müllenmeister 1988). "The Réunion dodo [...] must have succumbed to dogs, rats and pigs during the latter half of the eighteenth century" (Ley 1957b, p.44). The species still occurred in 1763 on Réunion (Luther 1970).

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[2] Brial (2006) noted that in 1704 the human population of Réunion was 734, mostly concentrated around the coast, at Saint-Paul, Saint-Denis and Sainte-Suzanne. Between 1704 and 1714 it was 1157 and by 1735 it was 8289. Also during this time there were many escapes of slaves to the mountainous areas. Brial added that if the Réunion solitaire survived until 1714-1735 then Billiard's statement might well have been correct.

Reasons for Species Extinction

- Habitat loss, fragmentation and/or degradation
- Stress (due to disturbance)[3]
- Predation (native or exotic, including hunting)[4]
- Competition for resources (native or exotic)[5]
- Decline in food availability and/or nutrition
- Climate (long term) and weather (short term) changes
- Changes in the populations and/or behaviour of other species (predators, competitors, interactors)
- Disease (including effects of pollution)

Altaba 2014

Altaba (2014) plotted a model of insularity syndrome (I) as a function of evolutionary potential (E) and dispersal potential (D) (Atalba 2014, fig.3). E is "the magnitude of a vector in the space defined by the inverse of generation time, the inverse of effective population size and population structure. These parameters may often be very difficult to assess, but they can be replaced by proxies" (p.48). D "for a particular taxon in a given context is the magnitude of a vector in the space defined by the dispersal probability at the appropriate spatial and temporal scale, range size and taxonomic diversity of its native community"; Altaba added that these can be "approximated by the ratio of the largest to the minimum (effectively a unit in most animals) distance covered by one individual in one year (d, in meters to meters), the species' extent of occurrence (o, in Km^2) and a rank of community diversity in one Km^2 (δ, from 1 to 4), respectively" (p.48). Needless to say, most of these parameters cannot be accurately assessed for the dodo and therefore Altaba must have estimated them for his analysis. Furthermore, he did not specify whether any proxies were used in the calculation of E, or what these were. As such, his results are of limited informativeness.

Altaba noted that "[a]t very low values of D, insular evolution should prevail, while at large values of D, the forces shaping strongly continental species must rule. Thus, I can be written as the addition of two terms:

$$I = \mathrm{f}(E)\,\mathrm{P}(D) + \mathrm{f'}(E)\,\mathrm{D}^2$$

The first term accounts for insularity, being the product of evolutionary change and a measure of isolation. This measure is a Poisson distribution of D, meaning chance dispersal into the system. On average, colonization of islands probably occurs only once, so the mean (λ) can be set to 1. The second term is the product of the rate of evolutionary change and dispersal potential in two dimensions (i.e., geographically).

The shape of $\mathrm{f}(E)$ can be approximated by a Gompertz function, a sigmoid curve that accurately describes biological growth" (p.49).

Localities where specimens of the Réunion Ibis (*Threskiornis solitarius*) have been found

Data from Brial (2006).

The Grotte des Premiers Français

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[3] The other factors listed here also lead to stress.

[4] Predation can also be a beneficial controlling factor, removing old, sick and genetically 'unfit' individuals from a population.

[5] Such as competition for food and habitat.

A cave under the cliffs south of Saint-Paul; it was excavated in 1974 by Bertrand Kervazo. Amongst the avian remains found was a tarsometatarsus identified as ciconiiform. Cheke (1987) noted: "The cave is known to have been used by early settlers, and so [...] Cowles's bone appears therefore to represent either a prehistoric extinction, or, more probably, the remains of a bird killed and salted elsewhere and eventually eaten on Réunion" (p.34).

Grotte de l'Autel
A small rock shelter at the foot of a cliff at Saint-Gilles-les-Bains. It was investigated in 1980 by Roger Bour and François Moutou. The avian bones included fragments which Cécile Mourer-Chauviré identified as ibis. However, she concluded that as none of the contemporary accounts corresponded to such a bird it may have become extinct soon after the arrival of man. Due to the robustness of the tarsometatarsus, it was named *Bourbonibis latipes*. Mourer-Chauviré later identified this 'ciconiiform' tarsometatarsus as ibis.

Marais de l'Hermitage
The site is in marshy ground on a flood plain, along the road to Hermitage-les-Bains. In October 1989 P. Kaufmann, owner of the land, contacted Harry Gruchet to survey the area prior to the construction of a botanical garden ("Jardin d'Eden"). In June 1992 Sonia Ribes, curator of the Muséum d'Histoire Naturelle, Saint-Denis, and a team of experts, including Roger Bour, François Moutou, Cécile Mourer-Chauviré and Pierre Esmiol, investigated the site further. Bird bones were rare. The stratigraphy was described by Sonia Ribes:

> From top to bottom we find: a dense layer of reeds, a substrate that gradually passes from humus to a very compact mud, made up of organic debris, sand, coral and basalt, the base is formed by coral and coral debris themselves fossils. This is where the bones lie pell-mell, protected by a very adherent mud matrix. Everything is flooded by ground water, water depth ranging from 30 to 70 cm (translated from Brial 2006, p.43).

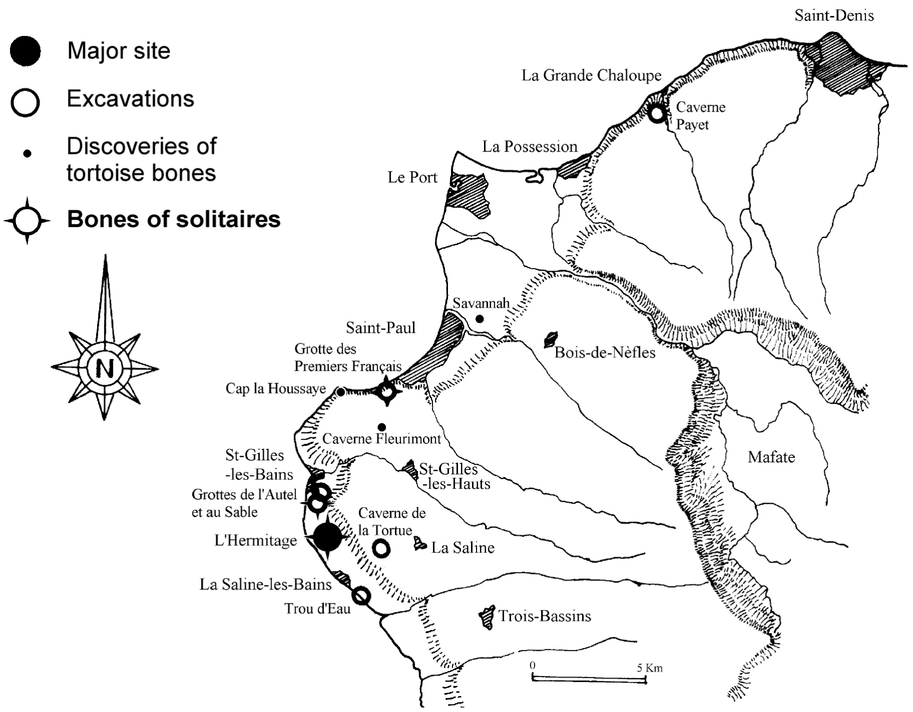
Jean-Michel Probst further described the site:

> On 20 August 1994, Roger Bour, Cécile and Roland Mourer-Chauviré, Sonia Ribes, Jean-Pierre Palencia and myself prospect an area of several square metres. In a hole about one metre deep, wading through 20 cm of water, we patiently dig the earth with a tool called "écarte coco" and with the fingers we extricate an unsuspected quantity of tortoise bone interspersed with blocks of fossil coral. This operation is generally undertaken just under the surface of the water, one must "feel" with one's fingertips the different elements that appear in turn as we move forward. This ossiferous layer is about 20 cm high. It is sandwiched between two distinct layers: above, by 70 cm of mud and silt, interspersed with deep roots and rushes down through a bed of coral sand which are mixed with numerous remains of shells (translated from Probst 1995, p.44).
>
> At the end of a few hours, we managed rather quickly to determine whether it was a piece of tortoise, coral, wood or bird bone. Then when I released for a moment a "layer" of fragments of tortoise carapace, I felt an unusual form which did not to belong to a tortoise. It was a lower mandible lower of a beak of bird slightly bent than the end. At the time I thought that it was either a beak of Curlew *corlieu*, or the endemic ibis or a species of rail still not described. [...] The beak "is wedged" between two pieces of backing (carapace of the tortoise) [...] It was found at a depth of 125 cm, within the lower limits of the ossiferous layer, just above coral sand (translated from *ibid*.).

During this investigation bones of the Réunion ibis were discovered, including a mandible fragment. Since 1992 there have been almost annual excavations and a total of around 90m^3 have been excavated.

Grotte de l'Autel
A small cave (3m^2) along Route Nationale 1 near Saint-Gilles-les-Bains. It was excavated in 1980 by Roger Bour and François Moutou.

The fossil sites of Réunion investigated so far amount to a small number and the majority are within a small area.



Map of fossiliferous localities on Réunion (edited slightly from Brial 2006, p.70).

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